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DESIGN OF A SLOT HEIGHT DISTRIBUTION FOR INCREASED HOVER CONTROL POWER ON A CIRCULATION CONTROL ROTOR

by

Daniel W. Poe

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AVIATION AND SURFACE EFFECTS DEPARTMENT

DTNSRDC/ASED-80/24

December 1980

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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distribution was constrained by a minimum practical slot height setting of 0.002 in. and a minimum unpressurized blade slot area of 3.0 in^2. Several distributions were evaluated. Noteworthy trends that emerged are: (1) A negatively tapered slot height distribution is favorable to producing hub moments in hover, and (2) a uniform distribution (zero taper) requires the lowest cyclic pressure for trim at 120 knots. The final distribution selection exhibited a 38-percent improvement in predicted hub moment over a slot height distribution previously used on the flight demonstrator.

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NOTATION

a	Speed of sound, fps
C_μ	Local momentum coefficient
c	Local blade chord, feet
h	Local slot height, feet
M_j	Local jet Mach number
$\dot{m}$	Local mass flow, slugs/sec
P_a	Atmospheric pressure, psfa
P_o	Local total blade duct pressure, psfa
q_∞	Local dynamic pressure, psf
S	Local blade area, ft^2
V_j	Local jet velocity, fps
γ	Ratio of specific heats, 1.4 for air
Δr	Local blade segment length, feet
μ	Rotor advance ratio
ρ_j	Local density of coanda jet, slugs/ft^3

ABSTRACT

The Circulation Control Rotor Performance Prediction computer program was used with the XH-2/CCR rotor configuration to determine a slot height distribution that would improve control power in hover without causing excessive cyclic pressure requirements for trim in forward flight. Effects of total slot area as well as distribution were considered. The final distribution was constrained by a minimum practical slot height setting of 0.002 in. and a minimum unpressurized blade slot area of 3.0 in^2. Several distributions were evaluated. Noteworthy trends that emerged are: (1) A negatively tapered slot height distribution is favorable to producing hub moments in hover, and (2) a uniform distribution (zero taper) requires the lowest cyclic pressure for trim at 120 knots. The final distribution selection exhibited a 38-percent improvement in predicted hub moment over a slot height distribution previously used on the flight demonstrator.

ADMINISTRATIVE INFORMATION

This study was conducted at the David Taylor Naval Ship Research and Development Center (DTNSRDC) for the Naval Air Systems Command under Program Element 63203N and Task Area W0578SL001.

INTRODUCTION

The Circulation Control Rotor (CCR) has been developed at DTNSRDC over the past ten years and has culminated in the XH-2/CCR flight demonstrator. The XH-2/CCR is a Navy helicopter retrofitted with a CCR to demonstrate the technology of controlling a helicopter using circulation control aerodynamics.[1*]

The CCR uses pneumatic blowing to vary blade lift in place of, or in combination with, the blade pitch angle. Cyclic blowing is substituted for blade cyclic pitch to produce rotor hub moments, and collective blowing is combined with

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*A complete listing of references is given on page 13.

collective pitch to produce rotor thrust.

The circulation control airfoil has a quasi-eliptical cross section with a slot on the upper surface of the trailing edge; see Figure 1. Pressurized air from the internal duct is ejected from the slot tangentially over the trailing edge. Due to a phenomenon called the Coanda effect, which is a balance between pressure and centrifugal forces in the jet around the trailing edge, this jet of air adheres to the trailing edge, entraining the upper surface flow and inducing circulation. This circulation, and hence lift, can be varied by regulating the airflow through the slot. The parameter to describe the airflow is the momentum coefficient (C_μ) defined as:

$$C_\mu = \frac{\dot{m}\, V_j}{q_\infty S}$$

where $\dot{m} = h\, \Delta r\, V_j\, \rho_j$

$$V_j = M_j\, a$$

$$M_j = \left\{ \frac{2}{\gamma-1} \left[\left(\frac{P_o}{P_a} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right] \right\}^{\frac{1}{2}}$$

$$S = c\, \Delta r$$

or

$$C_\mu = \frac{h}{c} \left(\frac{2}{\gamma-1} \right) \left[\left(\frac{P_o}{P_a} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right] \frac{\rho_j\, a^2}{q_\infty}$$

Here, C_μ is directly proportional to the slot height-to-chord ratio h/c. The loading on a blade section can be varied for a given blade pressure by a

change in the slot height, thus changing C_μ. The lift characteristics of a typical circulation control airfoil, as reported by Abramson,[2] are shown in Figure 2.

As with any airfoil, the lift due to angle-of-attack characteristics are affected by the thickness-to-chord ratio, thickness distribution, and camber distribution. These parameters also have an influence on the augmented lift (lift due to blowing) on a circulation control airfoil. In addition, the trailing edge geometry, slot location, and slot height-to-chord ratio affect the lift augmentation. Very large values of h/c can cause augmentation decreases of 20 percent or more; very low values of h/c also result in a loss of augmentation.

The overall performance of a CCR is affected by the radial distributions of all of the fundamental airfoil parameters in conjunction with blade twist distribution, chord taper, blade planform, and many other parameters that affect blade dynamic response. Unlike a conventional rotor, however, the aerodynamic characteristics of a CCR can be altered by adjusting the radial distribution of slot height. These characteristics interact with the blade's dynamic response which, in turn, affects the control moment that the rotor can produce.

The XH-2/CCR rotor geometry was obtained from an extensive analytical tradeoff using the CCR performance prediction program (CCRPERF), which had been correlated with model-scale rotor test data. The study was performed for hover and forward flight with the objective of minimizing power and cyclic control required for trim. The distributions of thickness-to-chord ratio, trailing edge radius-to-chord ratio, camber, twist, slot location, and slot height were evaluated, and a final geometry was selected. These basic performance tradeoffs have been reported by Wilkerson.[3]

Since the study by Wilkerson,[3] the full-scale rotor has been constructed by Kaman Aerospace Corporation and tested in the NASA Ames 40- by 80-ft wind tunnel. The computer program subsequently has been updated and correlated with the full-scale rotor data.

Given the XH-2/CCR geometry, it was desired to determine a slot height distribution that would maximize control moments in hover while maintaining adequate control margins at 120 knots. This task was done with the updated version of CCRPERF using aerodynamic considerations only. The pneumodynamics of the XH-2/CCR control system were not considered.

COMPUTER PROGRAM DESCRIPTION

The computer program CCRPERF was used for the analysis. Strip analysis is used to compute distributed loads on the blade. Blade flapping and lead-lag degrees of freedom, a spanwise quasi-steady distributed elastic twist degree of freedom, and pitch due to flap coupling are featured. The blade slot is flexible and expands with increasing pressure. A modified Glauert inflow model is used, multiplying the standard Glauert inflow by the square root of the ratio of local disc loading to average disc loading. The rotor is isolated, and has no force or moment contributions from other vehicle components.

The CCRPERF program is capable of predicting hub forces and moments for a given set of control settings, or of trimming to the control settings required for an arbitrary set of forces and moments. Only steady-state straight and level flight conditions can be analyzed. The program has been correlated against full-scale wind tunnel data for trimmed, 1-g flight for speeds from 50 to 150 knots (μ = 0.14 to 0.40).[4]

DESIGN

DESIGN POINT

Before the optimization procedure, selection of a reference slot height distribution and a design point was necessary. For simplicity, a slot distribution of uniform height was selected (Figure 3a). This uniform distribution had a statically-set slot height of about 0.010 in.

On the flight demonstrator, pressurized air is supplied to the blade by a centrifugal compressor which draws air directly from the atmosphere. This air experiences a temperature rise across the compressor resulting in a temperature difference between the inside and outside surfaces of the blade. The difference in temperature causes a thermal expansion of the slot height. The magnitude of this expansion has been empirically determined to be about 0.006 in. This value is added to the statically-set value for the analytical representation. The combination of statically-set plus thermal expansion yields an unpressurized slot exit area of 3.0 in^2 per blade. All slot areas in this report include the increase in area due to thermal expansion.

To maximize the control moment, the mean (or collective) pressure that would produce the largest hub moment had to be determined. Using the uniform distribution, the hub moment was evaluated for a constant cyclic input for a range of mean pressure. Figure 4 shows that a maximum sensitivity occurred near a mean pressure of 3200 psfa (pounds per square foot absolute). Next, the maximum cyclic pressure available was evaluated by assuming that (1) the minimum pressure obtainable was 1.5 psi above atmospheric pressure, (2) the maximum pressure corresponded to that of choked flow, and (3) the pressure varied in a pure 1/rev sinusoidal fashion (see Figure 5). With these assumptions, the maximum cyclic pressure available occurred at a mean pressure slightly less than 3200 psfa.

Since both the maximum sensitivity and the maximum cyclic pressure available occurred at a mean pressure of about 3200 psfa, the maximum hub moment would also be produced at this condition. Therefore, the design point chosen for maximizing hub moments at hover was a mean pressure of 3200 psfa with the maximum available cyclic pressure of 805 psf.

All analysis presented is for a vehicle gross weight of about 12,400 lb. A flat plate drag area of 27.5 ft^2 was used to determine the propulsive force required in the forward flight analysis.

RESTRICTIONS

Due to physical limitations with the existing hardware, certain restrictions on the final selection of the slot height distribution naturally occur. These restrictions, however, pertain only to the final selection and may be violated to evaluate trends.

The centrifugal compressor on the XH-2/CCR is equipped with a surge valve, which opens under adverse conditions to prevent compressor surge. To avoid surge valve activity, a minimum unpressurized slot area of 3.0 in^2 per blade must be maintained.

While maximum control power at hover is very important, adequate control margins must be maintained at forward speed. A maximum control setting corresponding to 60 percent of the maximum cyclic pressure was selected as a requirement for trim in level flight. A conservative value for the maximum cyclic pressure was assumed to be 750 psf. Using this value, the rotor had to be able to fully trim with less than 450 psf of cyclic pressure.

Because of difficulties in accurately setting very low slot heights on the flight demonstrator, a static setting of 0.002 in. was established as a minimum

slot height for the final design.

TRADEOFFS

SLOT AREA IN HOVER

The effect of slot area on hub moment was assessed by evaluating hub moments for a constant mean pressure and cyclic pressure, and a range of slot areas. Slot height distributions were obtained by scaling the uniform distribution, which has an area of 3.0 in^2 (Figure 3a), by constants ranging from 0.4 to 1.2. The results presented in Figure 6 indicate a significant effect from slot area. In fact, reducing the unpressurized slot area from 3.0 to 1.5 in^2 increased the resulting moment by 15 percent. Setting the slot area as low as possible would maximize control power in hover. A low slot area was also preferable from a performance standpoint, because it required a lower mass flow and consequently less compressor power. To avoid compressor surge valve activity, this area could not drop below 3.0 in^2. (The actual control valve characteristic is such that minimum blade pressure increases and maximum cyclic pressure decreases with decreasing slot area below 3.0 in^2, but not enough to change the trends shown in Figure 6.)

SLOT AREA IN FORWARD FLIGHT

The effect of slot area on the cyclic pressure required for trim was evaluated for forward flight. The rotor was trimmed in pitch, roll, thrust, and X-force using the uniform slot height distribution scaled by constants ranging from 0.40 to 1.73 at forward flight velocities of 60 knots and 120 knots; see Figure 7. The cyclic pressure required for trim at 120 knots decreased as slot area increased up to an area of about 4.5 in^2. However, relatively little benefit was gained above a slot area of 3.0 in^2. At 60 knots, a minimum was reached with a slot area of about

2.5 in^2 with very little increase at an area of 3.0 $in.^2$ A slot area of about 3.0 in^2 was therefore a fairly good selection from forward flight considerations.

SLOT DISTRIBUTION IN HOVER

The blade slot area was held constant to obtain a first-order effect of slot height distribution, and hub moments were evaluated for negative-, zero-, and positive-tapered slot height distributions (Figures 3b, 3a, and 3c). As shown in Figure 8, hub moment increases as the taper decreases. Negative taper indicates that loading the blade more inboard is favorable to the production of hub moments at hover.

A detailed study was performed to assess the exact sensitivity of the radial distribution of slot height. Analytically, segment slot heights were individually perturbed from their uniform value while all other segments were uniformly adjusted to maintain a constant slot area. Hub moments were evaluated for every other segment along the span for several values of slot height perturbation. The results of these perturbations are listed in Table 1. These results were used to generate two slot height distributions (Figure 3d and 3e) that were then evaluated for hub moment response. For comparison, these distributions are spotted on the graph of hub moment sensitivity to slot area in Figure 9. Several geometrically simple slot height distributions (Figures 3f through 3i) were also evaluated and are spotted as single points in Figure 9 for comparison. The predicted hub moment for one of the previous slot height distributions existing on the flight demonstrator (Figure 3j) is included in the figure as a reference for relative improvement.

The distributions generated using the results of the slot height perturbations (Figure 3d and 3e) showed hub moment increases of 45 percent and 37 percent with respect to the previous distribution on the flight demonstrator (Figure 3j). The

most negatively tapered distribution (Figure 3g) shows the largest increase with a 47-percent improvement. These results indicate that a slot height distribution that is high inboard and low outboard is the most favorable for producing hub moments at hover. Note that the distribution which is highest at the slot midspan and tapers to zero inboard and outboard (Figure 3f) produces about the same control moment as the uniform distribution. This is possibly due to the unfavorable low slot heights inboard counteracting the favorable low slot height outboard.

SLOT DISTRIBUTION AT 120 KNOTS

Several of the slot height distributions evaluated at hover were also evaluated at 120 knots to determine the amount of cyclic pressure required for full rotor trim. These distributions are spotted as single points in Figure 10. The parameter limits are also shown. Slot distributions requiring more than 450 psf of cyclic pressure for trimmed flight or with unpressurized slot exit areas less than 3.0 in^2 were unacceptable for the flight demonstrator. Figure 10 shows that the uniform distribution required less cyclic pressure for trim than distributions of the same area with either positive or negative taper. The exact reasons for this relationship have not been determined. Note that distributions with the same area and the same magnitude of taper require about the same amount of cyclic pressure for trim at this condition, even though their tapers are of opposite sign. Only the distribution of Figure 3f matched the uniform distribution, as was the case in hover.

SLOT HEIGHT DISTRIBUTION SELECTION

The final selection of an improved slot height distribution was based on total blade slot area and slot height taper. The factors considered in the area

tradeoffs indicated that a slot area of 3.0 in^2 was the best selection. Within area limitations, 3.0 in^2 yielded the highest control moments in hover for the uniform distribution. At both 60 knots and 120 knots, the required cyclic pressure for trim was near the minimum. This area also required the lowest mass flow and, hence, the lowest compressor power. When slot height taper was considered, the most negative produced the highest hub moment at hover. By combining these factors and maintaining the minimum slot height of 0.002 in, the slot height distribution of Figure 3k naturally evolved. This distribution had a slot area of 3.0 in^2 and was negatively tapered in a linear fashion to the minimum value at the tip of 0.002 in. The distribution required only 8 percent more cyclic pressure for trim at 120 knots than the uniform distribution (Figure 10), and at hover produced a hub moment 10 percent higher than the uniform distribution (Figure 9). This was a 38-percent increase in control power over the previously existing distribution (Figure 3j).

As shown in Figure 9, three other distributions (Figures 3b, 3d, and 3g) were predicted to produce larger hub moments in hover than the improved distribution of Figure 3k. All three distributions, however, had slot heights of zero at some point along the span, and thus could not be used on the flight demonstrator.

As a final comparison, the maximum hub moments were generated for a full range of mean pressure for the previously existing, the uniform, and the improved slot height distributions (Figures 3j, 3a, and 3k). Figure 11 shows that the improved distribution produced control moments that were slightly less than the other distributions at low pressures. However, this was outweighed by significant improvements at mean pressures above 2800 psfa. The distribution of Figure 3k showed a 10-percent improvement over the previously existing distribution (Figure 3j) at a mean pressure of 2800 psfa, 27 percent at 3000 psfa, and 38 percent at 3200 psfa.

CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to determine a slot height distribution for the XH-2/CCR rotor that would improve hover control power while maintaining sufficient control margins for trimmed level flight at 120 knots. At a mean pressure of 3200 psfa, the final selection exhibited a 38-percent improvement in hub moment over the distribution previously used on the flight demonstrator. This distribution was geometrically simple, and met the requirements on minimum slot height and blade slot area.

During this study, two notable trends emerged for the configuration analyzed: (1) negatively tapered slot height distributions are favorable for control power in hover, and (2) a uniform distribution was the best of those examined with respect to cyclic pressure required for trim at 120 knots.

The question of optimum slot height distribution for a CCR is quite complex (even under simplifying assumptions) and deserves further study.

REFERENCES

1. Kirkpatrick, D.G. and D.R. Barnes, "Development and Evolution of the Circulation Control Rotor," Paper presented at the American Helicopter Society 36th Annual Forum, Washington, DC (May 1980).

2. Abramson, J., "Two-Dimensional Subsonic Wind Tunnel Evaluation of Two Related Cambered 15-Percent-Thick Circulation Control Airfoils," DTNSRDC ASED-373 (Sep 1977).

3. Wilkerson, J.B., "Design and Performance Analysis of a Prototype Circulation Control Helicopter Rotor," NSRDC ASED-290 (Mar 1973).

4. Wilkerson, J.B., "The Circulation Control Rotor Flight Demonstrator Test Program," Paper presented at the American Helicopter Society 35th Annual Forum, Washington, DC (May 1979).

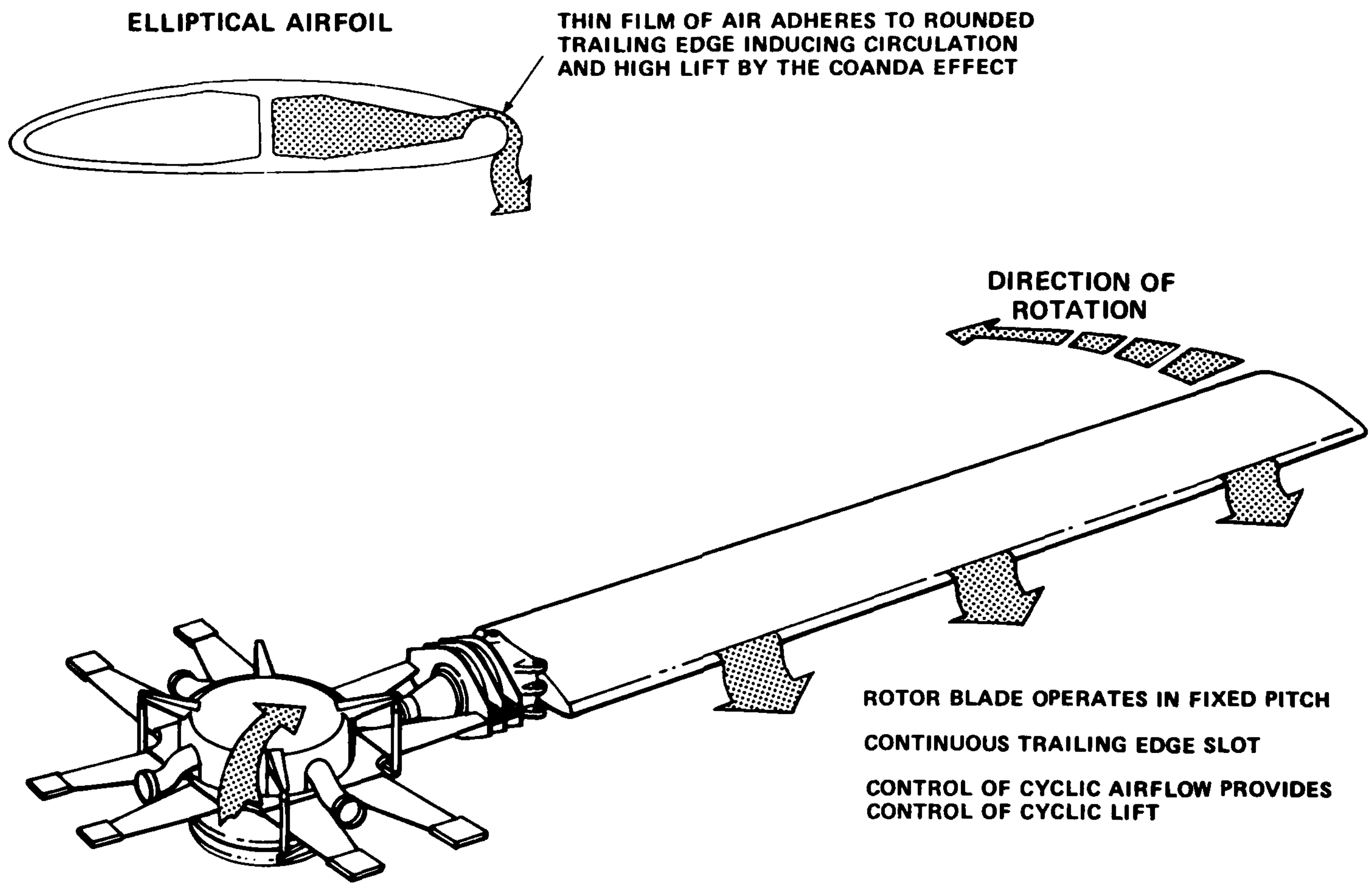


Figure 1 - Operating Principles of the Circulation Control Rotor

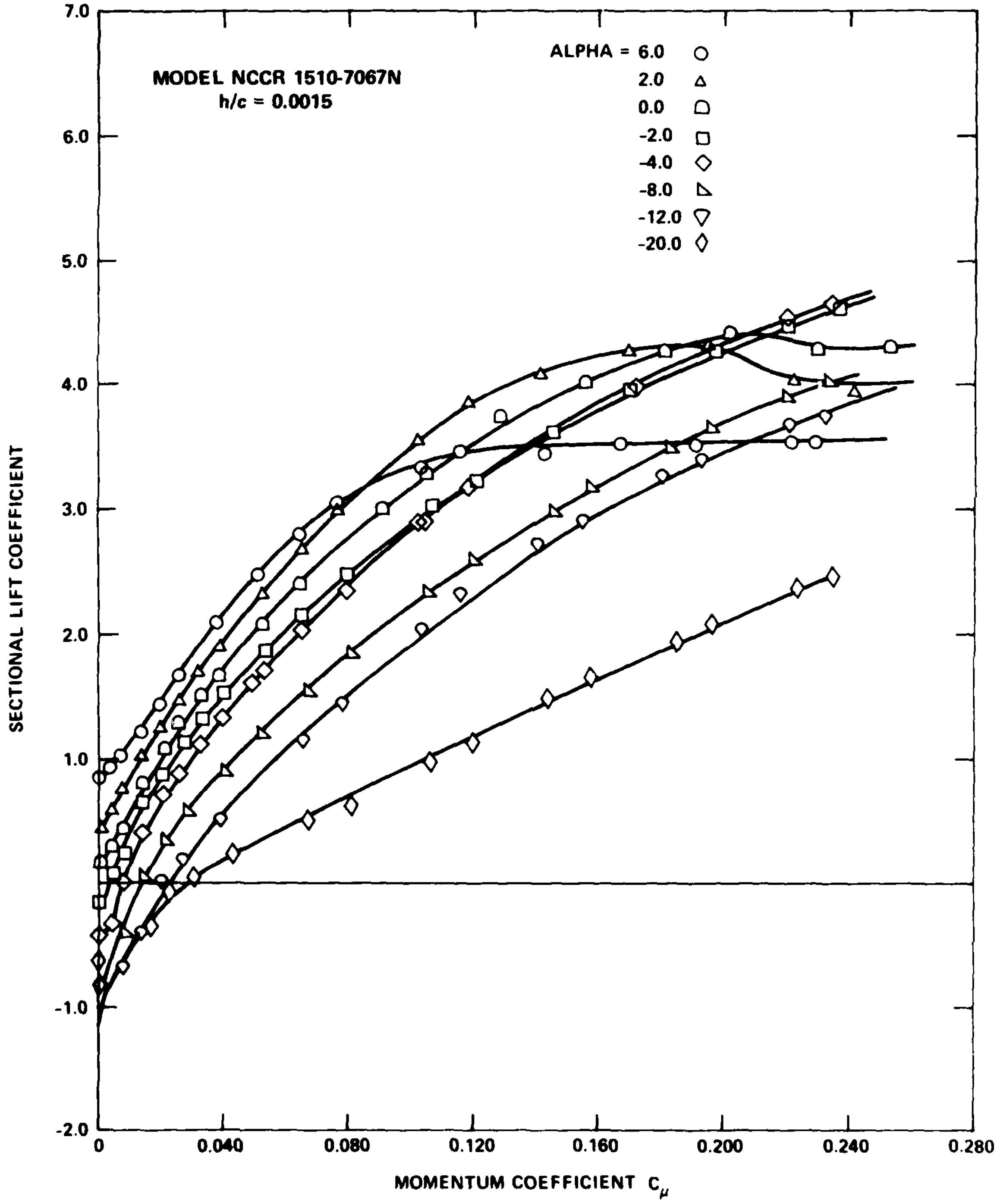


Figure 2 - Lift Characteristics of a Typical Circulation Control Airfoil

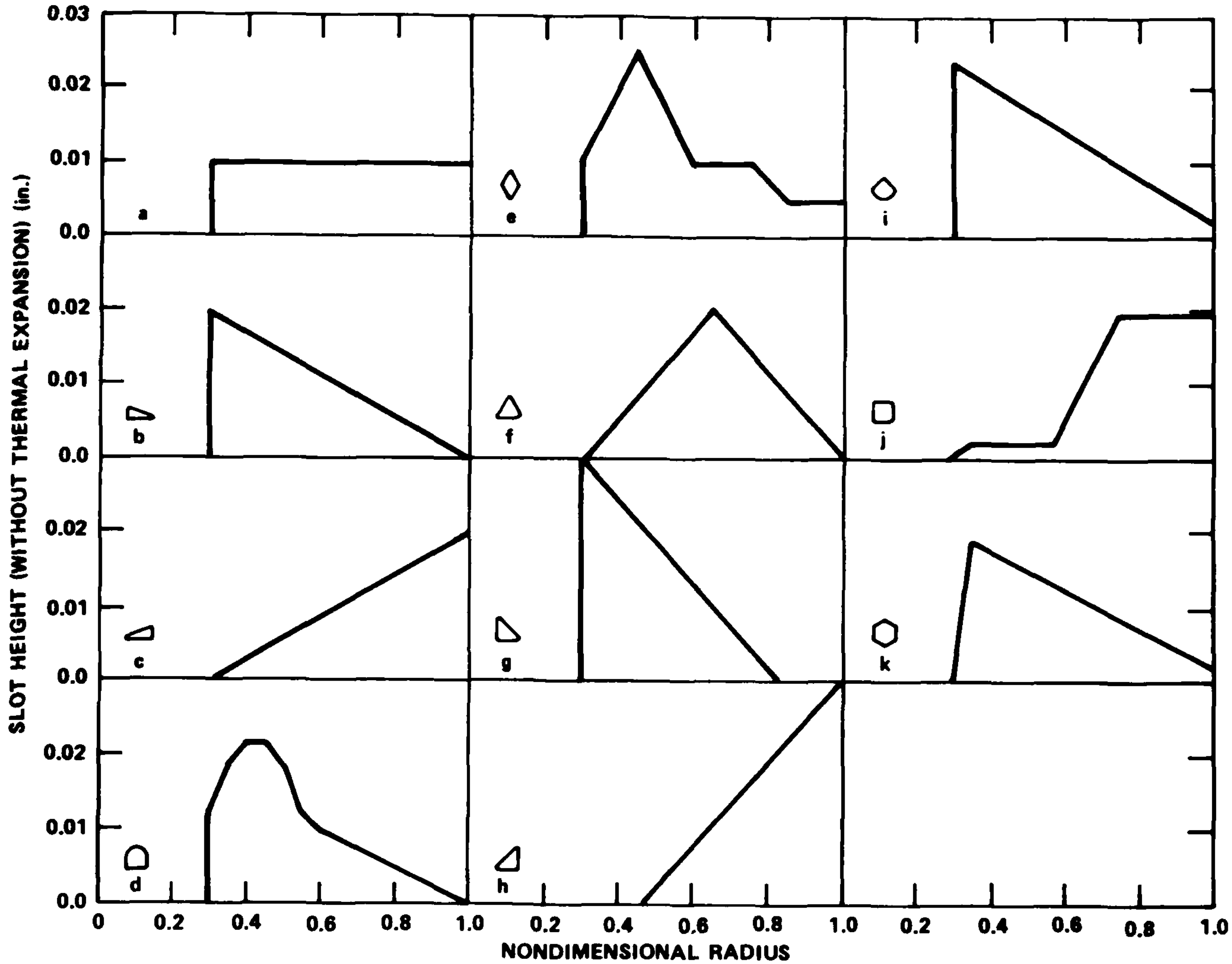


Figure 3 - Slot Height Distributions

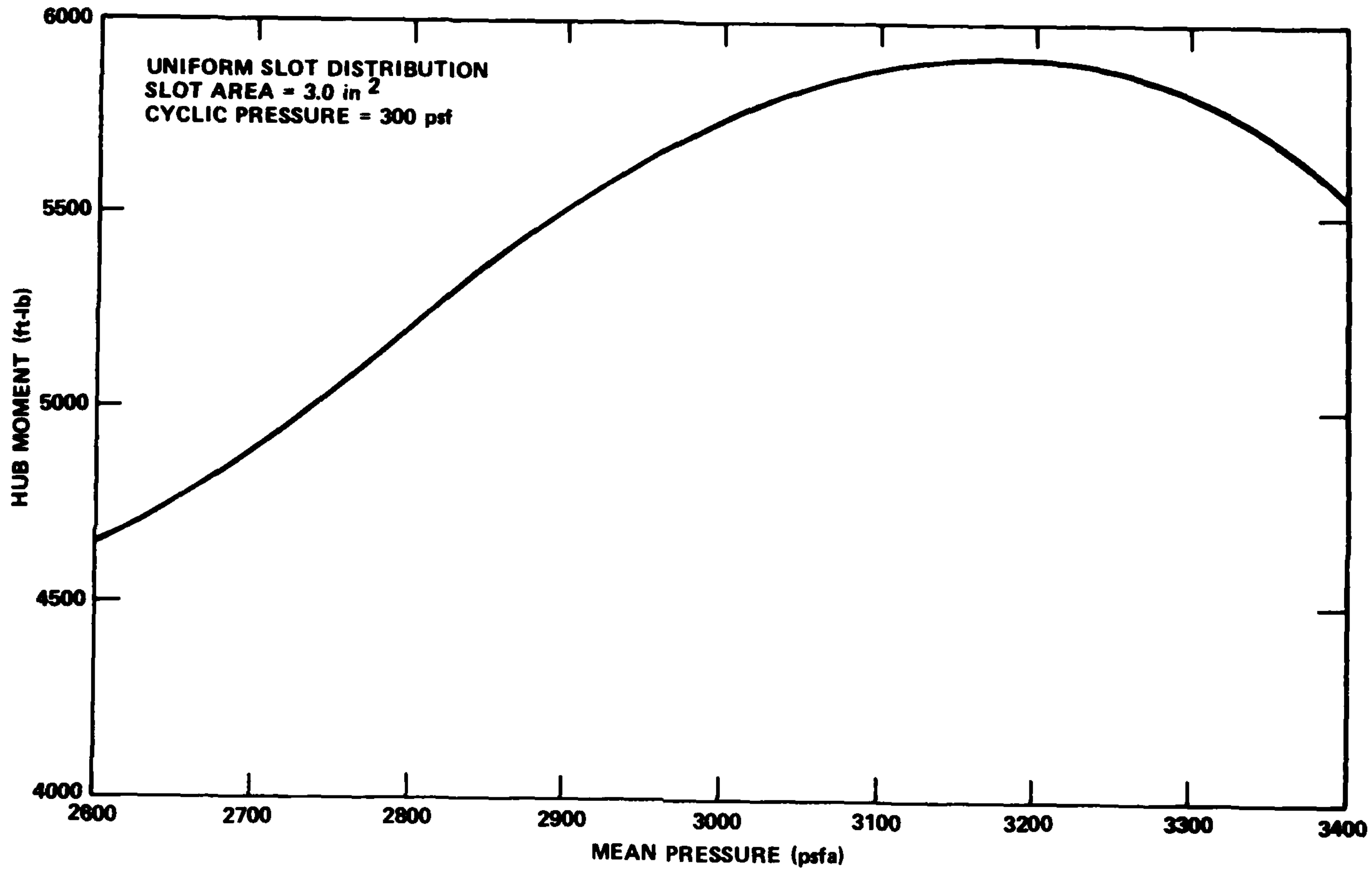


Figure 4 - Hub Moment Sensitivity to Mean Pressure

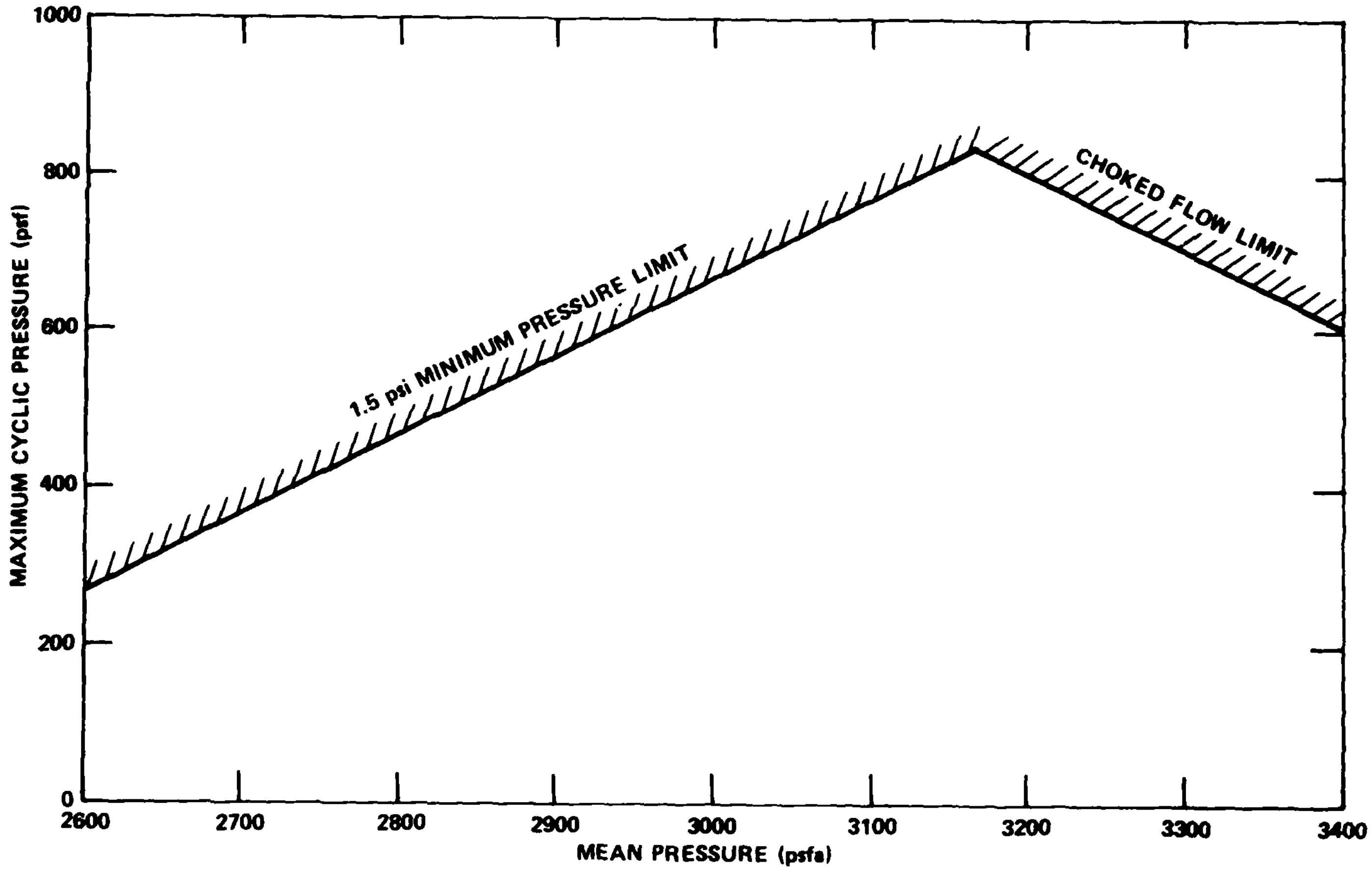


Figure 5 - Maximum Cyclic Pressure Available

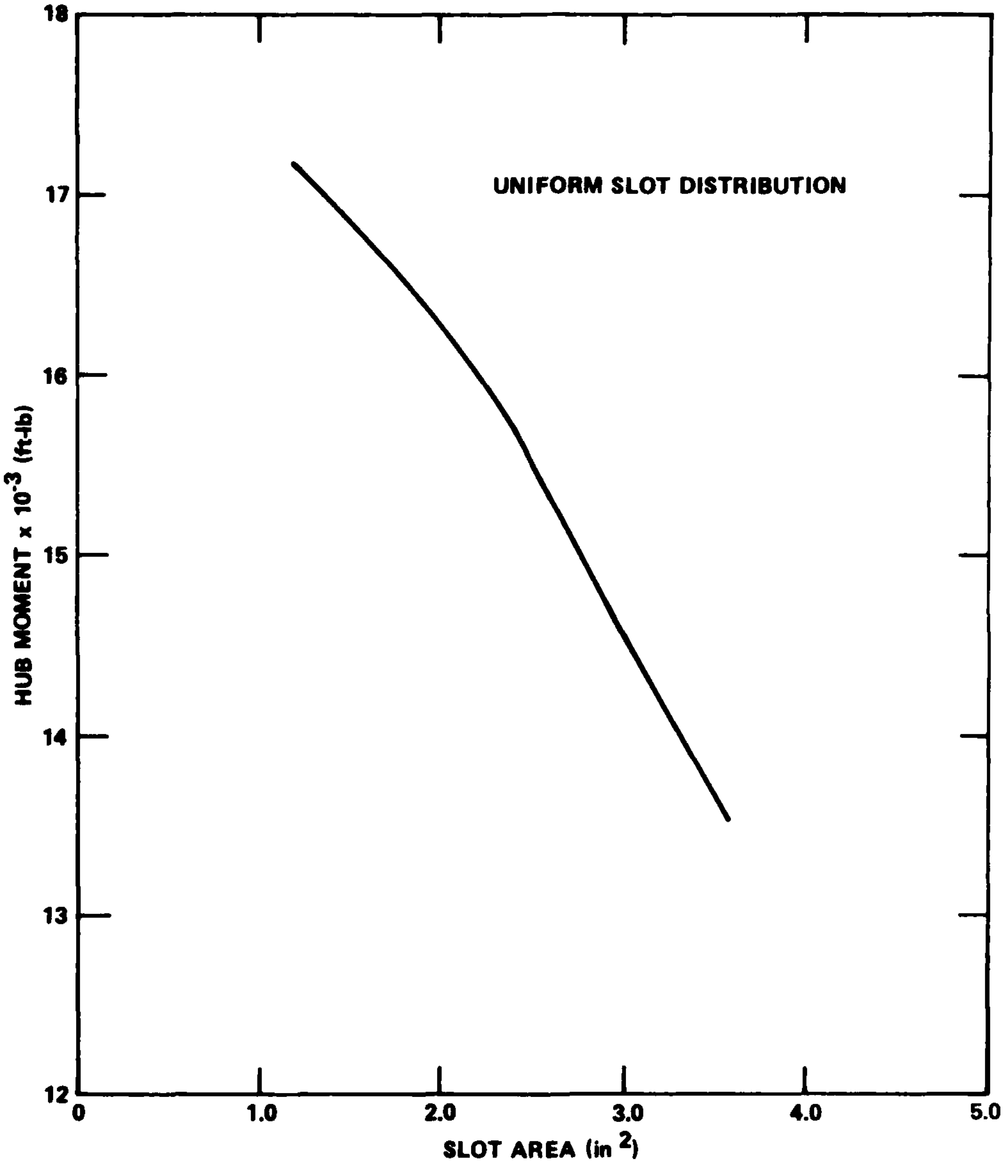


Figure 6 - Hub Moment Sensitivity to Blade Slot Area at Hover

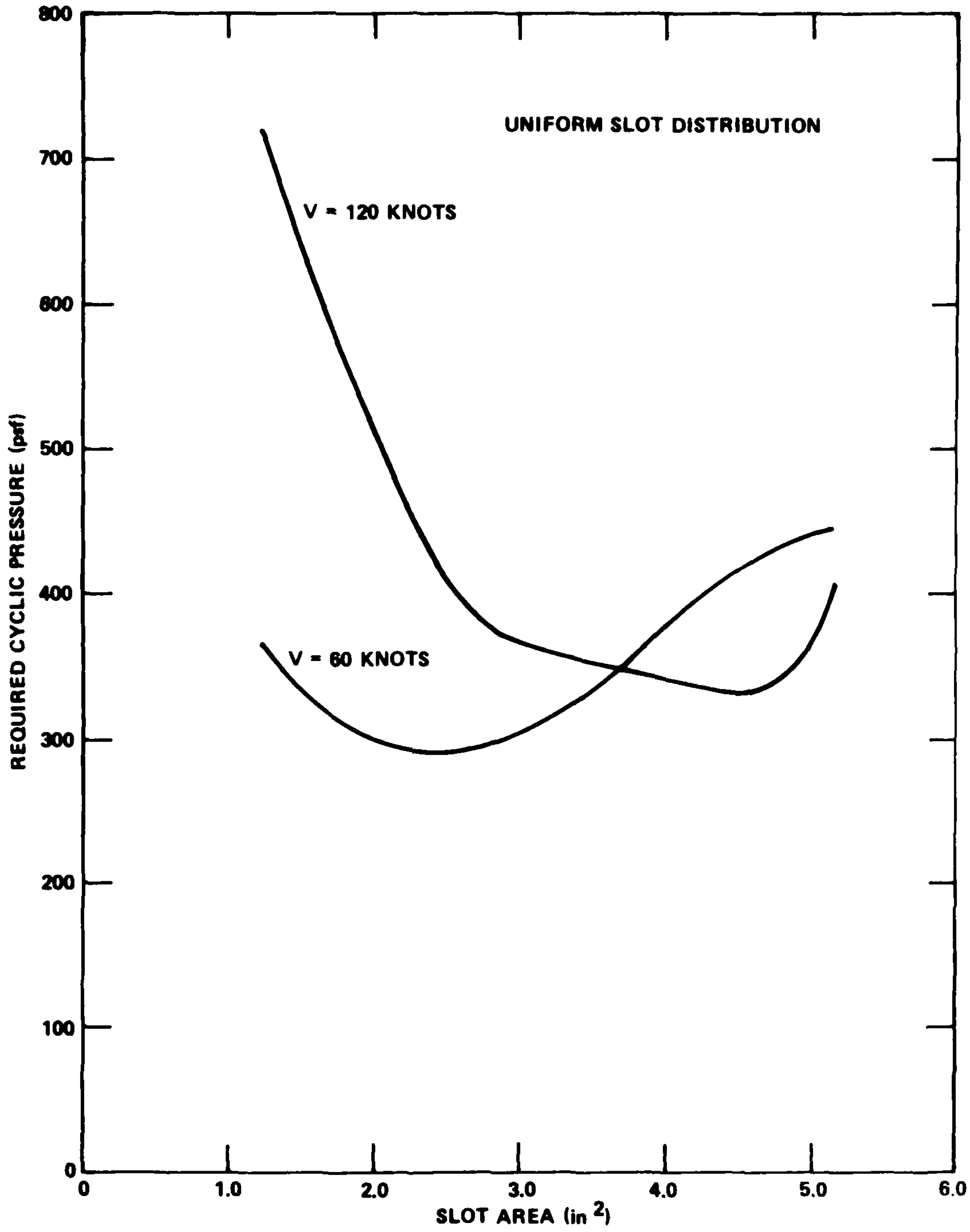


Figure 7 - Effect of Slot Area on Cyclic Pressure Required for Trim in Forward Flight

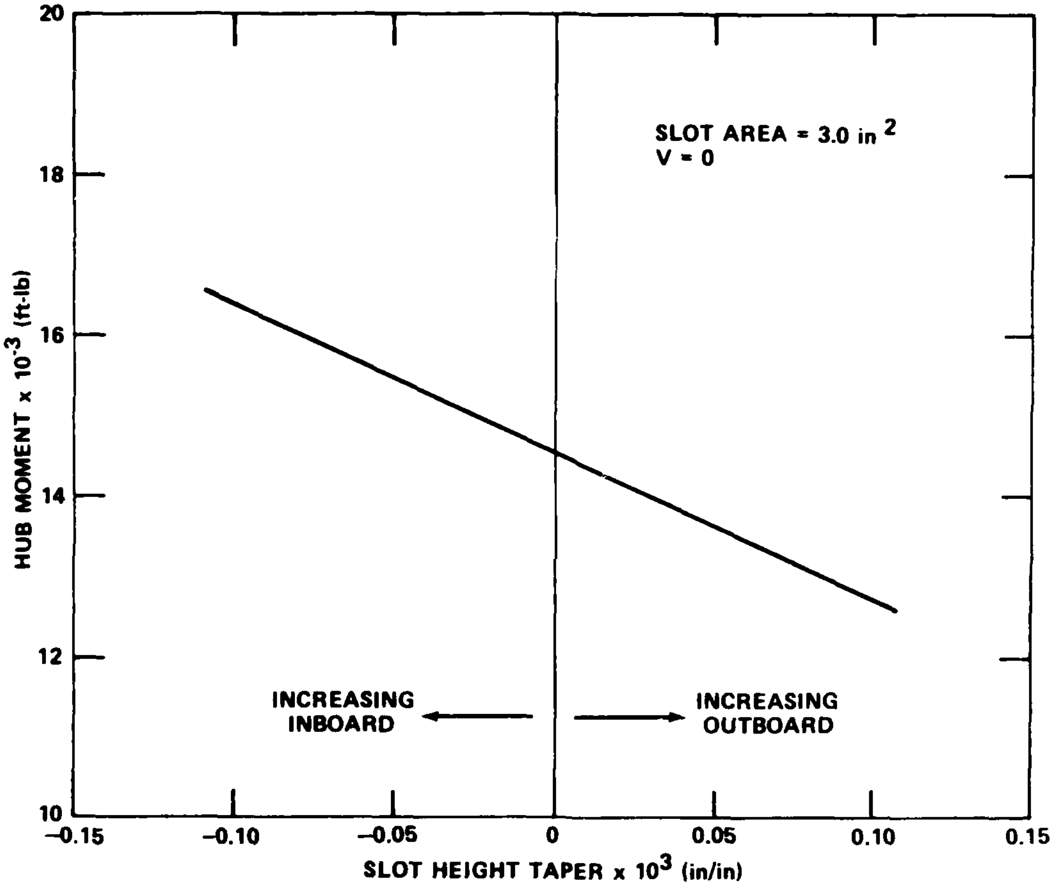


Figure 8 - Effect of Slot Height Taper on Hub Moment at Hover

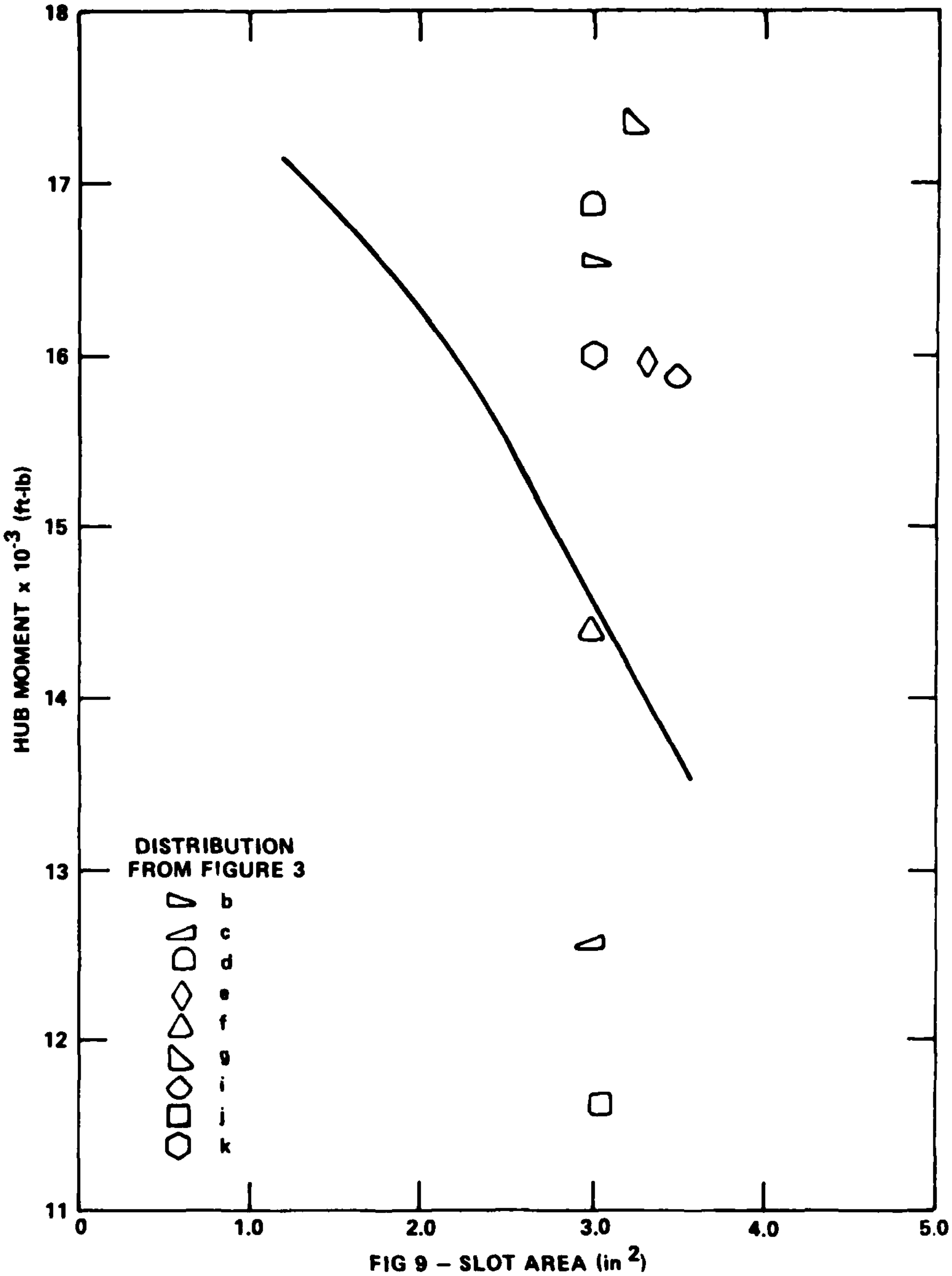


Figure 9 - Hub Moments Produced by Various Slot Height Distributions at Hover

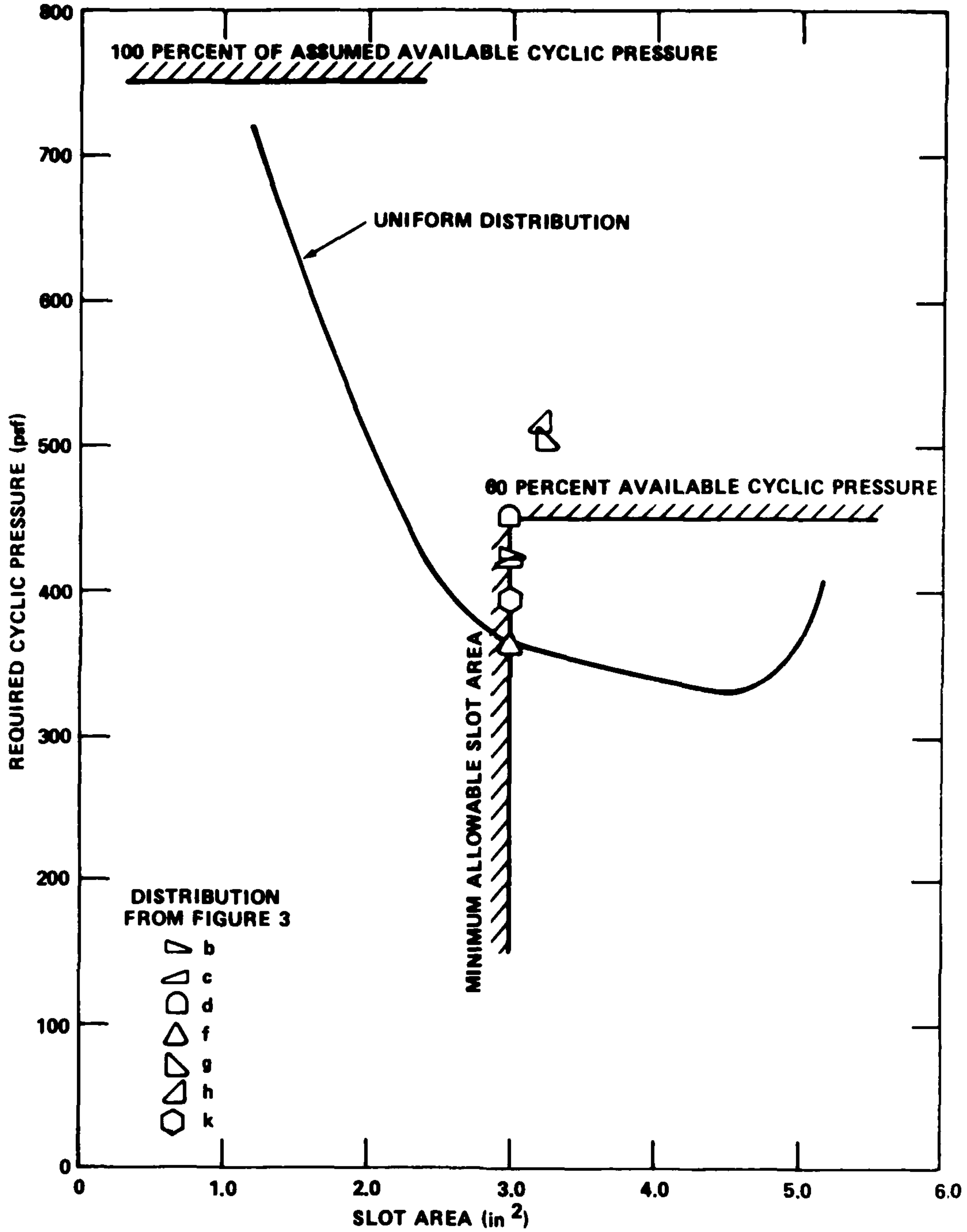


Figure 10 - Cyclic Pressure Required for Trim at 120 Knots for Various Slot Height Distributions

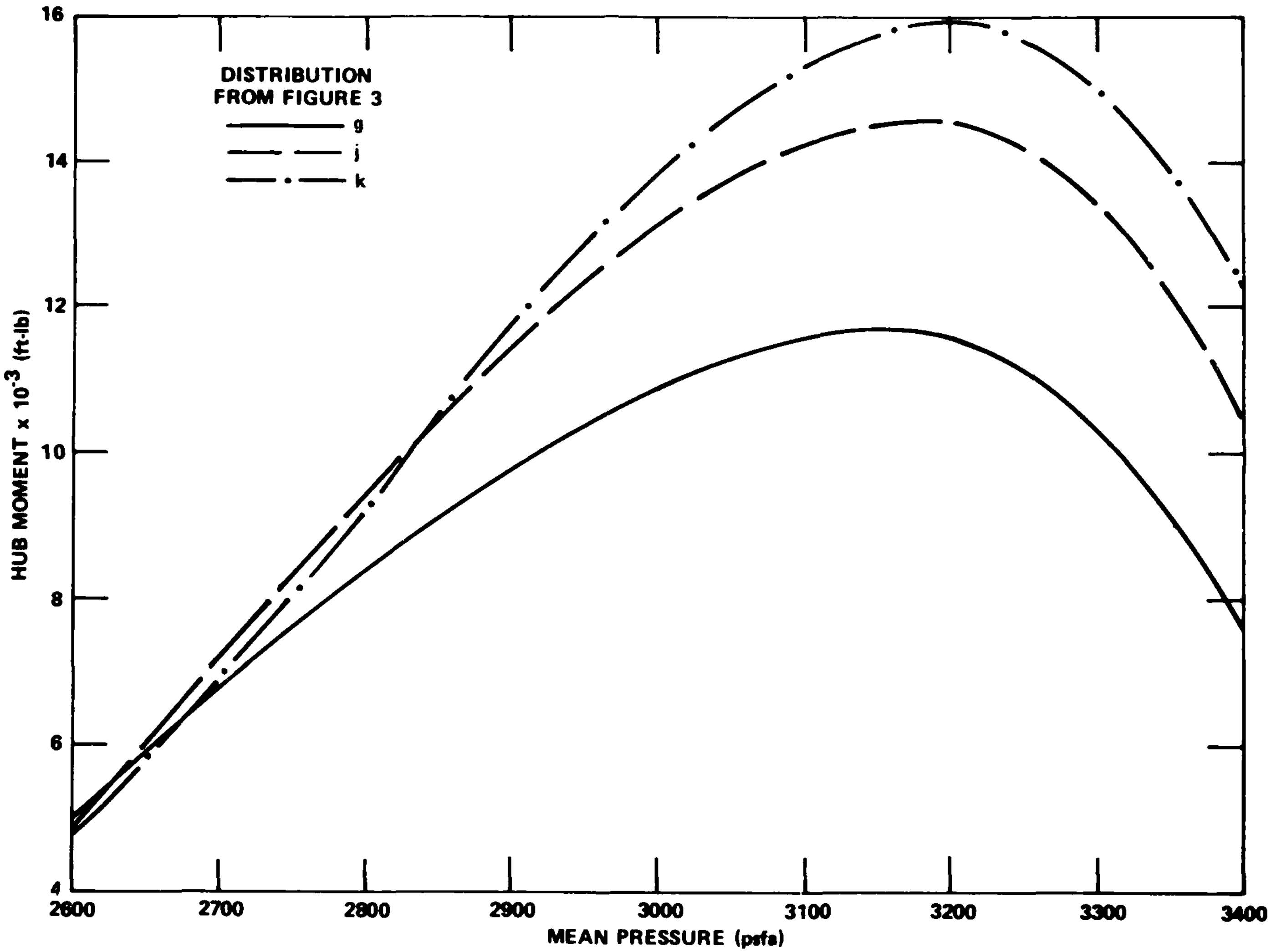
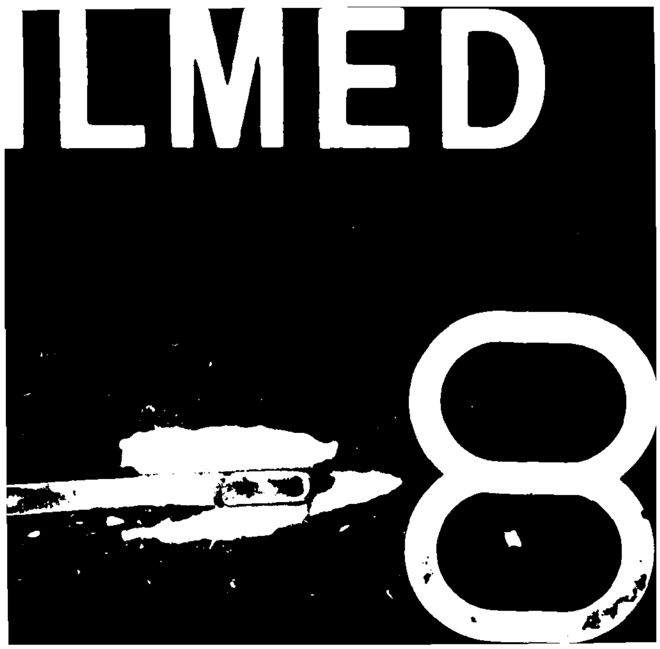


Figure 11 - Maximum Hub Moment

TABLE 1 - CHANGE IN MOMENT PRODUCED BY
SEGMENT SLOT HEIGHT PERTURBATION

NON-DIMENSIONAL RADIUS	MAGNITUDE OF PERTURBATION (in.)							
	-0.010	-0.005	-0.002	0.002	0.005	0.010	0.015	0.020
.325	-157	-82	-38	18	45	100	120	145
.425	-215	-107	-48	24	61	110	137	165
.525	-225	-96	-44	34	75	122	171	145
.625	-206	-74	-22	-22	4	-58	-128	-247
.725	-255	-84	-36	29	-106	-55		
.825	-125	26	48	26	-61	-401		
.925	-155	76	22	-11	-129	-455		

All Hub Moments in ft-lb

ILMED
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